Argonne NATIONAL LABORATORY

The Complex Systems Landscape of Future Urban Transportation

Our future urban landscape will "incorporate and expand connected transportation to ensure that connected transportation data, technologies and applications—as well as connected travelers—are fully integrated with other systems across a city, and fulfill their potential to improve safety, mobility and environmental outcomes in a complexly interdependent and multimodal world that supports a more sustainable relationship between transport and the city."

U.S. Department of Transportation

Imagine electric vehicles that drive themselves and communicate with one another, with batteries that both give and receive energy from the grid and surrounding buildings; cities with a range of transportation options, from automated taxis to light rail to on-demand buses and truck convoys, all aimed at decreasing travel time, maximizing energy efficiency and increasing safety; and an infrastructure conducive to electric vehicles and alternative fuels. While all of these things, and many more, are indeed possible, their development requires cutting-edge, multidisciplinary research.

This potential tidal wave of innovation calls for a novel framework with which to clarify and analyze the complex systems landscape of future transportation; one that can accurately inform technology R&D, policy decisions and market response beyond the traditional individual vehicle paradigm.

In an effort "to examine the nexus of energy and mobility for future transportation systems," the U.S. Department of Energy (DOE) has launched the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility consortium.

By studying mobility as a system researchers can predict future trends, an invaluable asset to policymakers as they prepare for the future of transportation. This enhanced prediction capability will enable researchers to design efficient technologies for reducing both consumer costs and greenhouse gas emissions by maximizing transportation assets with the larger transportation ecosystem.

Argonne National Laboratory's broad multidisciplinary expertise and world-class facilities enable this forward-looking and complex perspective. For example, researchers at the laboratory's Leadership Computing Facility will provide the advanced modeling knowledge necessary for mimicking future scenarios and the extraordinary computing power for processing and analyzing the massive datasets inherent in simulating dynamic systems such as transportation. And Argonne's Advanced Powertrain Research Facility, with its unique benchmarking and testing capabilities, will be essential in determining the energy impacts for a range of vehicle innovation. Argonne's unique capability to model the energy impacts of vehicles in a transportation system will also be employed.

Simply put, few places are better equipped to take on the unique challenge posed by DOE's SMART Mobility Program than is Argonne. By quantifying the benefits of these promising technologies, the nation's first national laboratory will guide their development and, by extension, the future of American transportation.

DOE's SMART Mobility Program

The U.S. Department of Energy (DOE) has launched the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility program "to examine the nexus of energy and mobility for future transportation systems." As one of the nation's premier research institutions, Argonne National Laboratory is well positioned to tackle the transportation challenges of tomorrow.

The SMART Mobility Program has five primary pillars—Argonne's research falls well within each:

- Decision Science
- Urban Science
- Connected and Automated Vehicles
- Multi-modal Transport
- Vehicles and Infrastructure

Transportation as a System

Research by the U.S. Department of Energy's (DOE's) national laboratories, including Argonne, suggest that better use of transportation assets and their roles in the broader transportation system could help meet national energy and greenhouse gas objectives.

Today's System:

- Vehicle-level focus
- Independent
- Unconnected
- Subject to human behavior and decisions

Tomorrow's System:

- System-level focus
- Connected
- Automated
- In concert with other vehicles and infrastructures
- Operated across modes
- Managed human behaviors and decisions

Argonne is exploring numerous untapped efficiency improvements aimed at reducing the use of fossil fuels and, by extension, the emission of greenhouse gases. The laboratory is helping DOE identify promising technologies for focused research, development and demonstration—from analytical modeling and systems to proof-of-concept to pilot-scale prototypical system validation in real-world demonstrations.

Argonne's Pioneering Projects in SMART Mobility

Argonne is out front in the journey towards SMART Mobility with many projects already underway. The laboratory's forward-looking perspective is revealing novel technology opportunities that will accelerate research in the five pillars of DOE's SMART Mobility initiative.

POLARIS

This agent-based traffic flow model predicts how an individual user's decisions influence transportation. With POLARIS, researchers can change road conditions spontaneously and quickly visualize the impact on traffic flow and infrastructure. Or, the model can predict how people might respond to a known congestion event. As new technologies and transportation policies are introduced and infrastructure evolves, agent-based models such as POLARIS will be critical in answering countless questions about how cities, vehicles and people respond.

Autonomie

This system simulation tool allows energy consumption prediction for a wide range of transportation technology scenarios, all of which are of interest to DOE's SMART Mobility Initiative. Far from using one generic value for the myriad of types of cars on the road, Autonomie can model energy consumption for every conceivable vehicle type and technology, providing policymakers with valuable information with which to maximize transportation efficiency and reduce America's carbon footprint. In fact, Autonomie boasts high-fidelity models for more than 300,000 vehicle configurations.

Array of Things

Argonne is partnering with numerous institutions, including the University of Chicago and the Urban Center for Computation and Data, on this urban sensing project aimed at public health and decision making that recently received a $3.1 million grant from the National Science Foundation. By monitoring pollution levels, light, sound, motion and traffic, to name a few, researchers hope to gain valuable insight into how people, and cities, react to one another.

Ann Arbor CAV Exploration

The laboratory has teamed with Idaho National Laboratory and the University of Michigan to equip 500 volunteer vehicles with data collection devices in an effort to gauge the fuel savings potential of CAVs and understand how drivers respond to increasing connectivity and automation. The effort recently received a $2.7 million grant from the U.S. Department of Energy.

Truck Platooning Demonstration Project

Argonne is providing in-kind support with instrumentation and analysis to the Texas A&M Transportation Institute in its quest to better understand and apply truck platoons or convoys, which show great potential in reducing the carbon footprint of freight delivery.

LakeSIM

Argonne researchers, in concert with the University of Chicago, are developing tools that merge urban design with scientific analysis to improve the decision-making process associated with large-scale urban developments. One such tool, called LakeSim, has been prototyped with an initial focus on consumer-driven energy and transportation demand. LakeSim began with the need to answer practical questions about urban design and planning, requiring a better understanding of the long-term impact of design decisions on energy and transportation demand for a 600-acre development project on Chicago's South Side—the Chicago Lakeside Development project.

Behavioral and Decision Science

Urban infrastructure spending is 50% higher than in other parts of the country and transportation costs for urban households can average up to $5,000 more annually.

Understanding why and how decisions are made by people is critical to realizing the SMART Mobility future. Tomorrow's transportation landscape will be determined by which technologies are adopted and how they are used—decisions that will in turn influence future direction. Modeling and incentivizing choices and modes of travel across the transportation ecosystem, from the individual to mass-transit options, will ensure both the efficiency and effectiveness of emerging technologies.

Only by understanding choice at the vehicle, individual and system levels can researchers and policymakers truly capture the complex interdependencies of future transportation systems.

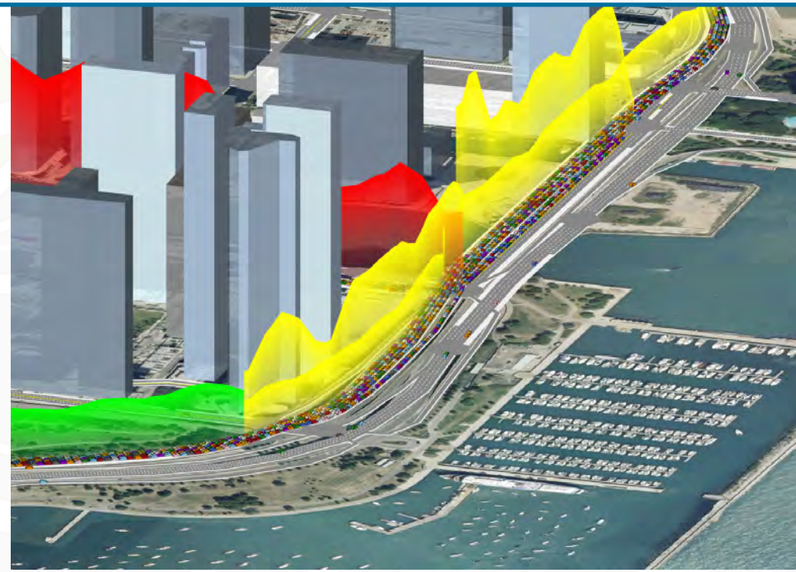
With more than three decades of experience in the area of decision science, Argonne has plenty to offer. As a thought leader in the field, the laboratory is regularly called upon to assist other institutions in tackling their most complex questions regarding the science of choice.

Argonne will bring informed and inspired decision making to our nation's transportation system planning using its whole-system analysis and advanced computing capabilities.

The laboratory's involvement in the Array of Things and its agent-based traffic simulator POLARIS are already revealing the ways in which our decisions will influence nearly every aspect of transportation. This data provides valuable insight needed by policymakers to realize the potential of SMART Mobility.

Via its decision science expertise and computing capabilities, Argonne will enhance models for:

- Vehicle choice and usage to ensure the adoption of EVs and other energy efficiency technologies, such as low carbon fuels to reduce greenhouse gas emissions
- Decisions across scale, from individual to ecosystem, that will be essential in informing policy, R&D direction and infrastructure investments
- The understanding of individual behavior and effects of future technologies on decision making



A POLARIS simulation of traffic flow in downtown Chicago.

Connectivity and Automation

CAVs could contribute $1.3 trillion in annual savings to the U.S. economy alone.

Few technologies have the potential to revolutionize transportation as do connected and automated vehicles (CAVs).

Automobiles that are largely self-operating and can communicate with one another promise enormous gains on all three SMART Mobility fronts: mobility, efficiency and safety. The numbers speak for themselves—the cost of time lost to congestion alone adds up to $120 billion annually, and automobile accidents total $871 billion each year.

Analyses by some DOE national laboratories have demonstrated that by 2050, CAVs could reduce greenhouse gas emissions by up to 90 percent; others have shown increases of up to 200 percent. This uncertainty has prioritized an expedited understanding of the potential energy impacts of this revolutionary automotive platform to guide a deployment with environmental sustainability.

Argonne is ahead of the game on CAVs with its Autonomie fuel consumption model, which, when paired with the laboratory's agent-based POLARIS traffic model, recently calculated the fuel savings resulting from a dedicated lane for tractor trailers in a busy corridor of Chicago.

These unique tools, along with both Argonne's automotive benchmarking and testing capabilities, will play a much larger role as CAVs evolve to achieve an optimal, reduced energy impact.

The laboratory's CAV work via Autonomie in Ann Arbor, Michigan, Chicago, Illinois and Detroit, Michigan, to name a few, and its partnership with Texas A&M's Transportation Institute are already exploring connectivity and automation in depth.

With its rich history of energy modeling and analysis, Argonne will advance DOE goals in CAV energy prediction and adoption by:

- Quantifying the fuel savings potential of CAVs across scales, from individual vehicle to national, for a range of potential adoption scenarios
- Ensuring that research data informs policy and best practices
- Identifying efficiency and optimization opportunities for vehicles and systems
- Aiding common practices for codes and standards for marketplace clarity

Argonne's modeling tools have found that a dedicated lane for tractor trailers on automated cruise control could produce energy savings of up to 40 percent.

Multi-Modal

More efficient transportation of people and goods can save over $70 trillion globally over the next 40 years.

For both people and goods, there can be numerous ways to accomplish the journey from Point A to Point B. With planes, trains, automobiles, buses and bikes all an option, understanding the most efficient combination of travel has enormous implications for both mobility and energy efficiency. As SMART Mobility technologies evolve, understanding the synergies between the numerous modes of transportation will be critical for maximizing their impact and reducing transportation's carbon footprint.

An early focal point is the freight industry. With petroleum usage by heavy duty vehicles expected to increase dramatically in the coming decades—from 26 percent today to nearly 50 percent by 2040—automating that sector early will have an enormous impact in efficiency for the entire transportation ecosystem.

Further energy insight will be achieved by integrating novel multi-modal transportation system models with real-world data and real-world application and demonstration. This will also require the incorporation of Argonne's decision science expertise as researchers seek to optimize and incorporate the surrounding infrastructure with various modality efficiencies.

And as cities continue to grow, understanding how people commute within them will be critical to maximizing mobility, efficiency and safety. Argonne's modeling work and the flexibility of its decision science package POLARIS have positioned the laboratory as a leader in quantifying multi-modality, including:

- Matching vehicle sizes with modes of passenger travel
- Quantifying the energy impact of travel modes and changes
- Analyzing effectiveness of policy incentives on mode choice and energy impact

With smart mobility, all modes of transportation will be seamlessly integrated to create choice for passengers with real time information.

Urban Science

For every 1 percent increase in EV adoption by 2030, there is a 7.4 million ton/year greenhouse gas reduction in the U.S.

Transportation doesn't exist in a vacuum. Rather, it is increasingly being integrated with other components of national infrastructure such as the electric grid, buildings and water, thus making cities vital in the quest for SMART Mobility.

By 2050 as much as two-thirds of the world will call cities home (compared with 50 percent today), and synergizing these interfaces will be critical in ensuring that cities are as comfortable and efficient as possible. This surge in urban populations across the globe will stress nearly every factor of urban life, and transportation in particular.

Calculating the energy impact of the numerous urban mobility technologies currently under development will be instrumental in urban planning, research that requires cooperation from and collaboration with state and local governments. As SMART Mobility evolves, so will America's urban centers, with function and design dependent on and complementary with existing and evolving transportation platforms. More immediately, however, cities will provide the perfect real-world laboratory with which to test the efficacy and adaptability of a range of SMART Mobility technologies and policies.

Argonne is already exploring SMART Mobility in urban environments via the Array of Things, the city-scale modeling project known as LakeSIM and CAVs in Ann Arbor, Michigan.

Argonne will continue to leverage technology and investments in urban sensing, data availability and urban infrastructure management systems while also developing "city-scale" models using robust data sets and frameworks to better understand the interfaces between transportation and infrastructure.

The plug-in hybrid and electric power supplies of CAVs have the potential to provide proxy energy storage for surrounding buildings and the larger grid.

Vehicles and Infrastructure

Advances in science and engineering tools are needed to understand the connections between buildings, people and transportation.

A substantial obstacle to the widespread adoption of electric and alternative-fuel vehicles is range anxiety. Both platforms require different supply chains for refueling/recharging and therefore must be carefully investigated for all future infrastructure investments. Revamping our largely petroleum-based infrastructure will be essential to the inevitable transition to alternative fuels and/or energy storage for electric vehicles, which in turn will both cut costs for consumers at the pump and greatly reduce greenhouse gas emissions.

This requires a new set of targeted, systematic analyses of regional transportation networks to enhance understanding of how vehicles and emerging alternative fueling infrastructures interact and how people use these investments. The effort will also require optimization tools for the simultaneous deployment of vehicles and fuels and real-world application in local testbeds that are investing in alternative fuel infrastructures. Argonne's modeling and simulation expertise will inform future infrastructure locations to maximize energy efficiency.

The laboratory's work in the CAV incubator in Ann Arbor, Michigan, its POLARIS simulation platform, its LakeSIM involvement and its partnership with Texas A&M's Transportation Institute are already exploring this critical vehicle/infrastructure nexus.

Argonne's Advanced Powertrain Research Facility's thermal test chamber is used to monitor electrical energy use in vehicle components, helping to optimize plug-in electric vehicles' energy efficiency.

The Right Place at the Right Time

The technological ramifications of SMART Mobility will not only transform transportation, but numerous other corners of the R&D universe as well.

According to DOE, "An expanded SMART Mobility Program will identify new areas for hardware and software research, including vehicle-powertrain optimization, ultra-lightweighting, new vehicle design, sensors, system integration, vehicle-infrastructure-system telecommunications, new manufacturing processes—including 3D printing and local assembly—and even high-performance computing for mobility applications."

The data and research results from Argonne's fundamental and applied R&D in these seemingly disparate research arenas will guide demonstration projects and advance the most promising technologies to a number of pilot communities where concepts will be tested, responses monitored and unexpected consequences identified. Only then can these solutions find their way to the marketplace and, ultimately, consumer adoption.

Measuring, testing and improving a system as complex and dynamic as transportation requires the greatest scientific minds and tools, making Argonne the right place, at the right time, to provide leadership for the SMART Mobility revolution.

Argonne researchers test a hybrid vehicle on one of the chassis dynamometer systems in the laboratory's Advanced Powertrain Research Facility, quantifying benefits for CAVs technology.

Artist rendering of Array of Things nodes mounted on city streetlight poles. The Array of Things is an an "urban sensing" instrument, measuring data on cities' environments, infrastructure and activities in order to scientifically investigate solutions to urban challenges ranging from air quality to urban flooding. Credit: Douglas Pancoast & Satya Mark Basu, School of the Art Institute of Chicago/Array of Things.

For Further Information

Ann Schlenker, Director

Center for Transportation Research

Argonne National Laboratory

aschlenker@anl.gov

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